Annual Report for ONR Grant N00014-90-J-1475.
Neutral Atom deBroglie-Wave Interferometry
Year 1, Feb. 1 - January 31, 1990
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ONR

Research Description:

The research program is to study the spatial wave-like character of freely propagating neutral-atom matter-waves (deBroglie waves). To do so, we are constructing and using a neutral-atom matter-wave interferometer. An atomic beam will be decelerated and cooled by conventional laser spontaneous cooling. It will be extracted from the laser cooling apparatus and fed through a series of micro-fabricated transmission gratings, which will serve as an interferometer, and thence to a detector.

Scientific Problem:

Matter-wave interferometry has here-to-fore been been performed with photons, electrons, neutrons, and Cooper electron pairs. Can this list be extended to include neutral atoms? What are the fundamental issues and constraints in doing so? Although the framework of quantum mechanics appears eminently successful in describing the micro domain of nature's building blocks, it is troubled by conceptual problems and counter-intuitive (or at the very least, surprising) predictions when it is applied to the macroscopic domain. Thus, its applicability within the macroscopic domain is frequently questioned and/or poorly understood. The experiments being performed will attempt to answer the above two questions, as well as to track the evolution of quantum systems in the macro domain, in a parameter range that spans their classical particle-like behavior through their quantum wave-like behavior.

The research is also useful in providing a new form of scientific instrumentation. If indeed a neutral-atom interferometer can be built, then a wide variety of fundamental problems become experimentally accessible. In atomic physics one will be able to measure complex atomic scattering amplitudes and measure spin-independent energy level shifts. In geodesy and geophysics and navigation, ultra sensitive measurements of

gravity, gravity gradients, rotation and acceleration will become available. A whole host of effects predicted by relativistic gravitational theory may become measurable. Finally, many predicted quantum topological effects and other counter-intuitive quantum mechanical effects in the macroscopic domain become measurable.

Scientific and Technical Approach:

The essence of our approach is outlined under Research Description, above. The apparatus consists of a three meter tall, vertical orientation, stainless steel, ultra-high vacuum chamber. It is mounted on a gimbaled vibration isolating framework. The lowest portion contains an atomic beam oven. Light from a diode laser is reflected off a 45° mirror with a slit in it, so as to counter-propagate along the atomic beam exiting the oven. The laser is amplitude modulated at an atomic hyperfine resonance and wavelength-chirped at a kiloHertz sawtooth rate. A decelerated, cooled neutral potassium beam should the emerge from the mirror's slit.

The cooled beam then propagates upward through a sequence of three micro-fabricated gratings. Grating positions can be manipulated through bellows seals. At each grating the beam undergoes wave-like diffraction and is thereby dispersed. The gratings are arranged to allow recombination of the dispersed waves so as to interfere and form a macroscopic standing matter-wave at the surface of the third grating. Upon transmission by the third grating, a Moire pattern is formed. The transmitted beam flux is monitored by a hot-wire detector. Upon manipulation of externally imposed fields (gravitational, Coriolis, magnetic, and/or electric) upon the matter-waves within the interferometer, and/or manipulation of the grating positions, the standing wave pattern may be detected and measured, via the resulting variation of the transmitted atomic flux.

Progress in 1990

Students:

Two PhD students have been brought onto the project. The first is Katie Schwartz, who was an undergraduate at MIT (there working in Dave Pritchard's lab). The second is Matthias Reinch, who was an undergraduate at University of Konstanz in Germany and also at UCSD. Matthias is currently supported on a US Dept. of Education Fellowship.

Vacuum System:

Reassembly of the vacuum system begun prior to the commencement of this Grant, and was completed in 1990. It included reassembly of the vibration isolation supporting framework, magnetic field coils, vacuum chamber, pumps, traps, ion and thermocouple vacuum gauges, automatic liquid nitrogen feed system, vacuum interlocks, and alignment telescope. Provision for future optical molasses transverse cooling/focusing of the beam, following its longitudinal "spontaneous" laser cooling was also incorporated. The vacuum system now routinely pumps to the low 10^{-7} to high 10^{-8} Torr range with neither bake-out nor LN trapping, and to the low 10^{-8} Torr range with LN trapping. With bake-out, a vacuum in the 10^{-9} range should be readily accessible.

Thermal Beam Generator:

To enhance production of low velocity atoms, a new isothermal (all copper) oven with sharp knife edge slits was designed and fabricated, along with an improved in-vacuum precision positioning platform for it. To further reduce its thermal gradients, the oven heater circuit was split into two separate circuits. New power and temperature monitor circuits were completed, installed and tested. The new oven produces a potassium beam that is easily detected with a hot-wire/electrometer detector more than 2 meters away. The oven is supported inside the vacuum chamber through bellows and can be positioned accurately using externally mounted dial gauges. Alignment of the oven to the beam line is now straightforward.

Vibration Isolation System:

Three generations of pneumatic support pistons were fabricated, installed, and tested, with each an improvement of the previous. Final system test currently awaits the next pump down. A summary report *Matter-Wave Interferometry Vibration Isolation* was submitted 3 October 1990. It is included as an Appendix.

Laser Systems:

A variety of diode lasers have been successfully temperature tuned using a single - stage thermoelectric cooler. To narrow the laser line-width, a cavity consisting of the laser itself on one end and a Littrow mounted diffraction reflection grating on the other (a design patterned after that by Wieman and Holberg) has been built and tested. It appears to perform exactly as advertised with a continuous tuning range of about 5nm and a measured line width of about 100kHz. In addition, we have been able to modulate the beam up to about 80 MHz. At higher frequency, RF pickup and diminishing photodiode frequency response prevented confirmation of the modulation, which we believe is still present.

To combine cooling with cavity locking, an insulated copper enclosure for the diode/grating cavity was fabricated. It included a vacuum sealed window to allow the beam to exit. It is cooled by two-stage thermo electric cooling. Unfortunately, minor difficulties were encountered at this stage. Presumably due to mechanical strains induced by mounting whole cavity on the second stage Peltier element (which is directly attached to the laser diode) the cavity lock is now insufficiently unreliable to allow it to run without continuous tinkering through the cooled enclosure. Some of the poor mechanical stability was due to the fact that since there was no equipment money in the first year, the cavity had been fabricated by students.

As a result of our tests, the whole cooled laser has been redesigned. The next generation lasers will be totally enclosed in vacuum with motorized positioners and commercial optical components. The first such vacuum enclosure has been built. Following acquisition of the optical components, the new lasers

will be tested (in the next quarter). Initial tuning checks will be with a potassium hollow cathode lamp via the optogalvanic effect. Following these tests, we will mount it on the vacuum chamber as a probe laser for the beam fluorescence experiments.

Additionally, in 1990, custom electronics for control of the Peltier cooling electronics and laser power supply have been fabricated. These were patterned after designs published by Weiman and Holberg.

Fluorescence Beam-Velocity Monitor:

One requirement for the experiment is to have a well characterized beam velocity distribution. To do so we have built a system for monitoring the fluorescence produced by the interaction of a probe laser with the potassium beam. Except for the probe laser, construction of this system is complete. Its components include fluorescence monitor optics and photomultipliers, as well as the probe laser transport optics and mountings. Experiments to measure the thermal velocity distribution from our oven and to detect the potassium hyperfine structure (allowing laser wavelength calibration) will commence shortly, once the probe laser is operational.

Matter-Wave Interferometry:

A report *Application of Fourier - Fresnel Imaging to Neutral - Atom Interferometry* describing progress in this area was submitted to ONR on 3 October 1990. A copy is included as an Appendix. A publication of this result is in preparation.

Matter-Wave Gratings:

Planning for the installation and fabrication of matter-wave gratings has proceeded. Recently, Virginia Semiconductor announced the availability of 1μ thick Silicon waffers. Instead of the silicon - nitrite gratings discussed in previous reports, we now envision fabrication of the gratings by plasma etch through such waffers. These may then be contact bonded to more substantial silicon waffers, which will provide a frame for support. The Engineering school at UCB (Cory Hall) has a facility for

performing most of these operations on campus.

Presentations:

In this quarter, the following presentations of the project's work were given:

1. NSF sponsored workshop on the Foundations of Quantum Mechanics. (Travel to this workshop was on the personal funds of the PI, and lodging and meals at the workshop were covered by NSF.)
2. LBL Research Progress Meeting.
3. Two UCB Physics Department Quantum Optics Seminars.